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EXECUTIVE SUMMARY — FATES AND EFFECTS OF DRILLING FLUIDS AND CUTTINGS DISCHARGES IN LOWER COOK INLET, ALASKA, AND ON GEORGES BANK

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FATE AND EFFECTS OF DRILLING FLUIDS AND CUTTINGS DISCHARGES IN LOWER COOK INLET, ALASKA, AND ON GEORGES BANK

EXECUTIVE SUMMARY

BACKGROUND

The prospect of major exploratory drilling for petroleum hydrocarbons off the northeast and northwest coasts of the United States has generated concern from regulatory agencies, the fishing industry, and citizens alike, regarding the extent to which such activities might affect marine ecosystems and resources, Drilling fluids and formation rock cuttings comprise the majority of the material discharged from offshore drilling vessels. These materials could impact marine environments either through direct burial of bottom organisms, toxicity of mud components or contaminants including trace metals, biocides, and petroleum hydrocarbons, or through changes in.the physical quality of the environment (e.g., suspended sediment load in the water column or grain-size distribution of sediments).

In 1977 a lawsuit was brought against the Department of Interior by the English Bay (Alaska) Native Corporation, the New England Fish Company, and several environmental groups regarding impacts of the proposed lower Cook Inlet OCS lease sale. As part of the settlement of that suit, it was agreed that an analysis of the toxicity of drilling mud and cuttings to lower Cook Inlet organisms would be performed by the Bureau of Land Management (BLM). In partial response to this provision, BLM funded this study of the likely fate and potential impacts of drilling fluids and cuttings discharged in lower Cook Inlet. Recent controversy over potential exploratory drilling impacts on Georges Bank led to expansion of the scope of this impact analysis to include that area.

OBJECTIVES

Specific objectives of this study were to:

1. Review information on the physical-chemical properties of drilling muds and their behavior in seawater (transport, dilution, deposition, flocculation, chemical transformations, etc.) and, based on this, define potential biological concerns.

2. Synthesize information available from previous studies on the physical and chemical fates and biological effects, both ●cute and chronic, of drilling muds and cuttings.

3. Eased on (1) and (2), define potential critical pathways of drilling muds end their constituents within lower Cook Inlet and Georges Bank. ●nd infer potential and probable ecosystem effects. Recommend any studies which should be performed to test hypotheses regarding these potential effects.

The following paragraphs summarize study results and conclusions as" well as potential areas for additional research.

PROPERTIES OF DRILLING FLUIDS AND THE DRILLING PROCESS

Drilling fluids or "muds" are essential to controlled and efficient drilling and seine many diverse functions to that end. Among the most important are the removal of cuttings from the hole, control of formation pressures, and lubrication and cooling of the drill bit and drill pipe. A wide variety of naturally occurring minerals (e.g., bentonite, barite), simple chemicals (e.g., sodium hydroxide, sodium bicarbonate, potassium chloride), complex organic compounds (e.g., lignosulfonates, formaldehydes, and other materials is combined to form the drilling fluid for each well. As a result there is a wide array of compositions that can be called "whole drilling muds," even for a relatively specific category of wells (e.g., offshore wells 3,000 m in depth or greater). Drilling fluid composition is also altered with depth within a" given well to counteract increasing formation pressures and to compensate for higher temperatures and other complexities. This variability greatly complicates prediction of impacts and comparisons between impact monitoring studies. For example, estimated total quantities of barium discharged from two recent offshore wells were 2,270 and 436,160 kg.

Extensive laboratory testing has demonstrated that the bulk of materials present in drilling fluids (e.g. , barite, bentonite) are relatively nontoxic chemically but contribute to high suspended solids levels. Other materials present such as heavy metals, biocides, and petroleum hydrocarbons may be highly toxic. They may also accumulate in tissues and potentially could be passed to higher trophic levels although biomagnification has not been demonstrated for drilling fluids.

During the first 50 to 150 m of drilling, cuttings are discharged directly at the seafloor, probably forming the nucleus of a cuttings pile in most environments. After a conductor pipe has been set, circulated mud and cuttings are returned to the drilling vessel. Each vessel is equipped with several mechanical devices to clean cuttings from the mud to allow recycling of the mud back into the hole. Coarser cuttings are discharged essentially continuously during drilling at relatively low rates . Larger volumes of mud and finer cuttings require discharge periodically at much higher rates, but for relatively short periods--from a few minutes to 3 hr.

Drilling fluids and cuttings discharged in the waker column offshore 'have been shown to separate into two relatively distinct components: an upper plume containing liquids and finer silts and clays; and a lower plume containing the bulk of discharged solids, cuttings, and caked or flocculated muds. Each of the plumes has its primary effects on a different component of the marine biosphere. The upper, or near-surface, plume may ● ffect drifting or free-swimming (planktonic or nektonic) species of the mid to upper (pelagic) portions of the water column while the lower or bottom-impinging plume affects benthic and demersal species living in, on, or in close association with the bottom. A variety of models has been used with varying success to describe the physical behavior of these discharges.

BEHAVIOR AND POTENTIAL BIOLOGICAL EFFECTS

Pelagic Impacts

All field and modeling studies reported to date have indicated that high rates of dilution of drilling fluids in the surface plume, on the order of 10,000:1, occur within a relatively short distance (e.g., 100 m) of the discharge. Several investigators have found that in areas of relatively low current all water quality parameters measured (e.g., temperature, salinity, dissolved oxygen, suspended solids, transmittance, and trace metals) approach background levels within about 1,000 m of the discharge except for suspended solids. The surface plume gradually settles at greater distances. In an environment of much stronger currents (viz., lower Cook Inlet), a measurable decrease in water transmissivity was reported across a narrow plume at distances in excess of 10 km from the discharge point with dilution occurring relatively more slowly beyond the 10,000:1 achieved at 100 m.

Within the zone a few meters downcurrent of the downpipe, whole mud concentrations exceeding measured 96-hr LC_{50} values* for many species could be experienced infrequently for 15 min to 3 hr by species actively swimming to maintain themselves in the plume. The likelihood of significant numbers of nektonic organisms remaining in this area long enough to suffer mortalities or other irreversible stress is considered remote because of the limited size of the near-field discharge area and the intermittent nature of the high-volume discharges. In the zone from a few meters to 100 m from the discharge, whole mud concentrations exceeding measured 96-hr LC_{50} values for the most sensitive species and the most toxic muds tested to date could be experienced infrequently, again for up to about 3 hr, by active swimmers choosing to maintain themselves in the plume. The likelihood of this occurring is somewhat less remote given the known tendencies of fish to congregate around offshore rigs but is still very low. The limited duration and frequency of these high volume discharges would again make the likelihood of significant mortalities or stress extremely remote. Beyond 100 m from the discharge, although concentrations will not drop as rapidly, they will be further reduced below 96-hour LC_{50} values for any tests reported to date. Thus, no acute effects are likely in this region.

Organisms remaining within a few meters of the discharge during routine, near-continuous, low-rate discharges could receive a long-term exposure to concentrations that approach those found to be lethal to the most sensitive organisms bioassayed to date. Probably few, if any, nektonic organisms would remain in this near-field dilution zone long enough to experience a lethal dose from continuous discharges occasionally interspersed with higher volume discharges. However, in areas with relatively moderate currents such as some parts of Georges Bank, fish congregating around the drilling vessel could experience some degree of sublethal stress unless they actively avoided the plume. Degree of avoidance or attraction of motile organisms to drilling muds has not been adequately explored. In any case, only a negligible

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*The 96-hr LC_{50} is that concentration causing mortality of 50 percent of organisms tested in 96-hr exposure.

fraction of the population of any given species in the region of the drilling activity would be at risk to such sublethal stresses.

Planktonic organisms would receive a maximum exposure to drilling effluents if, once entrained in the plume at the downpipe during a bulk discharge, they remained in it during its dilution and dispersion by currents. Exposure to this type of rapidly declining dose has not been attempted in laboratory tests. However, available data suggest a slight possibility that the high initial concentration would cause scme mortalities of crustacean plankton, including shrimp and crab larvae, particularly if they 'entered the plume at a highly sensitive stage of ecdysis (molting). Sensitivity of fish eggs or larvae to drilling fluids has not been reported in the literature but is likely to be no greater than that of larval crustaceans. The percentage of any planktonic population potentially affected would be negligible because of the narrow width and depth of the discharge plume and the brief duration and low frequency of mud dumps of this volume at any well.

In summary, based on all available information, it appears that the likelihood of significant impacts on pelagic plankton and nekton from drilling mud and cuttings discharges is remote, both in lower Cook Inlet and on Georges Bank. The potential ●xists and remains to be explored that some rig-associated fish could incorporate some heavy metals into their tissues.

Benthic Impacts

The degree of impact of drilling fluids and cuttings on benthic and demersal species is highly dependent on a number of local environmental variables (depth, current and wave regimes, substrate type, etc.) and on the nature and volume of the discharges including cutting sizes and the depth of the downpipe. Impacts can be considered to fall into two relatively distinct categories: short-term effects of mud toxicity and burial by mud and/or cuttings; and longer term effects of chemical contamination and physical alteration of the sediments.

The extent of the seafloor area where accumulation rates of cuttings and mud are great enough to cause stress or mortalities to benthic or demersal organisms (either due to burial or toxic ●ffects) will vary with the above-mentioned factors. Extremes would range from the situation described for central lower Cook Inlet, where dynamic conditions precluded formation of any cuttings pile and where cuttings were widely dispersed and entrained vertically into the seabed, to the situation existing in the Gulf of Mexico where cuttings piles typically about 1 m in height and 50 m in diameter have been reported. At the *d-Atlantic exploratory well the sone of visible cuttings was 150 to 170 m ●cross.

In very dynamic areas, both in situ bioassays ●nd benthic sampling have shown little evidence of effect on infauna or on epibenthic crustaceans ●t distances of 100 m or greater from the well. However, even in these very dynamic ●zeas, nearly complete disruption of benthic communities within 25 to SO m of the well must be assumed due to seafloor discharge of cuttings during placement of the collector pipe and due to placement of the baseplate, if used. In moderately deep water (100 m and deeper) with moderate or low currents, a patchwork pattern of muds and cuttings accumulations may occur and be accompanied by significant reductions in infauna in areas where accumulations are most evident.

The severity of the impacts due to burial is inversely related to the hydrodynamic energy level of the area, but the areal extent of the impacts is directly related to the area's energy level; thus, in low-energy environments a severe impact will be felt by infauna over a small area, but in higher-energy environments lesser impacts (partial mortality, changes in species composition) will occur over larger areas.

Motile epifauna (including demersal fish} is unlikely to suffer any direct mortality and may be attracted to the rig vicinity by the disturbance and increased food availability. On the other hand, changes in the physical or chemical nature of the bottom may preclude use of the area for some critical biological activity, for example by increasing the content of fines in coarse sediments used for spawning. Local reductions in productivity of infaunal prey organisms will also affect epibenthic species.

Effects resulting from physical alteration of the bottom, e.g., cuttings or mud accumulations that change sea floor topography and/or grain size, will tend to revert toward their predrilling conditions at a rate directly proportional to the rate at which natural processes are affecting the bottom. In an area such as the central portion of lower Cook Inlet, currents are so strong that no prolonged accumulation of mud or cuttings is possible. Cuttings are entrained into sandwaves of approximately similar particle sizes moving along the bottom and finer materials, including muds adhering to cuttings, are picked up by the currents and dispersed widely from the drill site. Within a very short period of time (a few weeks) it is unlikely that mud or cuttings would be detectable at the drill site.

At less dynamic sites, where cuttings and mudcake discharged exceed sizes transportable by normal bottom currents, return to predrilling conditions will occur more slowly. In shallow waters, severe storms will resuspend mud and disperse cuttings, working them into the finer ambient bottom sediments. In deeper waters, where little wavsurge is felt, biological activity will mix drilling deposits with natural sediments, and natural deposition of coastal sediments will continuously dilute cuttings and mud. However, many years may be required before overburden completely isolates the drilling deposits from biogenic reworking.

Presence of cuttings is unlikely to have any significant ●dverse ●ffect other than very localized burial of some infauna. The 300 m^3 of cuttings produced from a typical well, if spread evenly 0.5 cm deep, would cover ●n area of 60,000 m^2 (6 ha or 14.8 acres) perhaps killing a majority of infauna present and significantly ●ltering its future character (not necessarily ●dversely) due to increased coarseness of materials. This assumed area is considerably larger than the largest area of visible cuttings accumulation reported in the literature. Within one to several years the cuttings and their ●ssociated impacts would likely be undetectable in most environments due to resuspension and transport and to working of cuttings into the bottom.

Physical effects of drilling muds deposited on the bottom will be short-lived. However, presence of significant mud concentrations in the surficial sediments could be expected to have significant adverse effects on the existing infaunal community and could inhibit settlement of many types of organisms (e.g., Tagatz et al. 1980). The persistence of drilling mud in the surficial sediments is again dependent on degree of current and wave surge felt at the bottom, as well as biogenic activity. This material is expected to be rapidly dispersed horizontally (within a period of a few months) by bottom currents, and vertically by biogenic activities, even in the leas dynamic areas of lower Cook Inlet and Georges Bank. Nonetheless, mortality or loss of recruitment in key species could occur over a limited area, potentially affecting benthic species composition for 1 to several years. . .

The majority of benthic impact studies to date have found little. evidence of significant physical, chemical, or biological effects extending beyond 800 to 1,000 m downcurrent from a well site. However, reports available from a mid-Atlantic well monitoring study leave open the possibility that significant reductions in benthos and increases in trace metals levels may have extended up to 3,200 m or farther downcurrent from the well site. Since this is the only deep water (>100 m) study reported to date, and until clarification of its apparent results can be obtained, a considerable degree of conservatism has been imposed on impact analyses of deep water wells in environments with relatively low near-bottom energy regimes.

A discharge of 500 m^3 of mud solids from an entire 3,000-m well spread evenly 0.5 mm deep would affect an area of 1,000,000 m^2 (100 ha, 50 acres) assuming (very conservatively) that there is no removal of mud from the area during the duration of the well. In reality, in all environments much of the material will be dispersed beyond the limits of detectability before completion of the drilling (e.g., Meek and Ray 1980). It can be concluded that, in moderate- to low-energy environments, accumulations of cuttings and muds on the bottom have the potential to cause relatively severe impacts on infauna up to perhaps 100 to 200 m downcurrent of the discharge and less severe changes in species composition and abundance perhaps as far as 1 to 3 km downcurrent.

In addition to these relatively short-term acute, albeit localized, effects, chemicals present in the drilling muds may be ingested by bottom-feeding organisms and become incorporated into their tissues. The heavy metals arsenic, barium, cadmium, chromium, lead, mercury, nickel, vanadium, and zinc may increase up to one to two orders of magnitude above background in sediments within 100 m of the drilling rigs. In ● ddition to ● environmental variables, the ● u.rce and metals content of components comprising the mud system in use, ● s well ● s the chemistry of the formation being drilled, govern the relative increases in these various metals. At greater distances (to 1,000 m downcurrent) more ● lmmlant chemicals may be increased to perhaps one order of magnitude or less above background.

Quantities of metals discharged in the course of a typical well (e.g., some 1,378 ± kg chromium, 33 kg lead) would produce concentrations of 1.38 and 0.033 g/m^2 total chromium and lead, respectively, if spread evenly over 1,000,000 m^2 (assuming very conservatively that all metals are in the bottom-impinging plume). If uniformly mixed with the top 5 cm of sediment this would result in en elevation of total chromium in the sediment of about 17 mg/kg and 0.4 mg/kg for total lead. The value for chromium is on the same order of magnitude as, and the value for lead is an order of magnitude less than, background values (using total digestion) off the northeastern U.S. coast (ERCO 1980) and would be unlikely to cause significant biological effects.

Regardless of the rate of the dispersion process and degree of detectability, virtually all additions of metals to the marine environment will remain there, in some form, indefinitely. The only real significance of such additions, however, is in the degree to which they reduce the "fitness" (ability to survive and reproduce) of local organisms, or the degree to which they accumulate in the tissues of local organisms and are transmitted through the food web, affecting the "fitness" of the receptor. Two studies indicate that in order to attain the same body burden of a heavy metal, the concentration of the metal in particulate form must be two or more orders of magnitude higher than if the metal were in solution. This is an area in which additional and very sophisticated study is needed. The majority of the total metals discharged with drilling fluids and cuttings is in forms that are essentially biologically inert. However, some fraction of metals released is in biologically available forms. Several studies to date have shown elevated tissue levels of barium, chromium, lead, and mercury in organisms in the proximity of drilling mud discharges. At the present time, the significance or effects of heavy metals accumulations in animal tissues is largely unknown as is the relationship, if any, between these metals accumulations and histopathological or physiological, changes in the receptors. Although our present ability to interpret the significance of accumulations of metals in animal tissue is limited, it appears that significant effects due to drilling fluid discharges are unlikely beyond 3 km downcurrent of a discharge site.

CRITICAL PATHWAYS AND POTENTIAL ECOSYSTEM EFFECTS

Lower Cook Inlet

Cook Inlet is a large tidal estuary located in south-central Alaska on the northwest edge of the Gulf of Alaska. The lower inlet is characterized by wide tidal variations, complex net circulation petterns (including the presence of tidal rips), and large seasonal variations in inflows of fresh water, much of it containing high concentrations of fine-grained glacial sediments.

Cook Inlet contains marine biological resources of considerable economic, ecological, social, and esthetic value. Moreover, the biological productivity of lower Cook Inlet may be a major energy source for neighboring ecosystems. Many of the economically important organisms in lower Cook Inlet are members of, or dependent on, the benthos (i.e., organisms that live or or on the bottom). Clams, amphipods, and polychaetes (sea worms) are often abundant and provide a food resource" for larger predators such as king, tanner, and Dungeness crab as well as shrimp, Pacific halibut, and other fish. Distribution of organisms on deep water bottoms is often irregular with concentrations in some areas but few of the same species in adjacent areas. These distribution patterns are poorly understood for many species but are often in response to substrate type, depth, current, recruitment patterns, and food ● vailability.

Exploratory drilling in lower Cook Inlet to date has failed to detect commercial quantities of hydrocarbons. Although some additional wells may be drilled in the next few years, the chances of a significant discovery appear low. However, another OCS lease sale (No. 60) includes Shelikof Strait to the south. Moreover, drilling in state waters around the periphery of the inlet may also result in additions of drilling fluids and cuttings to the inlet.

The hydrodynamic regime in the majority of lower Cook Inlet is ideally suited to minimize the impact of drilling fluid and cuttings discharges. Strong surface currents will rapidly dilute the upper plume of fluids and finer particles such that no impacts will be felt in pelagic plankton or nekton. Cuttings impinging on the bottom will be rapidly dispersed and worked into the bottom sediments by near-bottom currents and biogenic activity. Mud solids will be scrubbed from the cuttings, resuspended, and transported from the site.

Only in the southern and northeastern portions of the Cook Inlet lease area will bottom conditions allow accumulations of mud and cuttings that could affect benthos. Cuttings and possibly mud accumulations could reduce benthic infauna and attached epifauna over a limited area (up to 60,000 m^2, less than 15 acres per well). In the deeper areas of the southern inlet dispersion of mud and cuttings could take several weeks or months and there is a potential that changes in species composition and abundance could occur over an area as large as 1,000,000 m^2 (250 acres). However, episodic high currents reported in these deeper waters would resuspend muds and transport them from the area. Thus, any observed impacts should be relatively short-lived, e.g., 1 to 2 yr.

The ultimate fate of the majority of drilling fluid solids and associated contaminants released in lower Cook Inlet will be distribution over the bottom of Shelikof Strait between Kodiak and Afognak Islands and the Alaskan Peninsula. Quantities of mud released under the BLM (1976) development scenario, if spread evenly over this area, would be undetectable chemically and insignificant biologically.

Georges Bank

Georges Bank comprises ● n area of about 25,920 km^2 off the northeast coast of the United States, east-southeast of Cape Cod. The bank is shallowest in its northwestern portion where the depth may be 5 to 6 m in areas such as Cultivator and Georges Shoals. Extending to the east and south of the shoals, much of the bank ranges in depth between 60 ● nd $0 m. Georges Bank circulation is complex with the principal feature being a clockwise gyre around the bank In water less than 60 m deep.

The gyre may not be entirely closed in all seasons, but most of the water within the gyre may be recirculated. Near-surface flows over deeper water (and entrained pollutants) may leave the bank at four locations: the northwest corner of the bank east of the Great South Channel, the eastern edge of the bank adjacent to Northeast Channel, the southern flank of the bank, and the southwest corner of the bank adjacent to Great South Channel. Subsurface flows may also leave the bank at four locations: in deeper waters on the steep northern flank, at the north- ● astern corner, along the southern flank, and at the southwestern corner.

The flow of water along the southern flank between 60 and 100 m is primarily along the isobath. It has been estimated that 70 percent of this flow leaves the bank at the southwest corner and crosses the Great South Channel where it continues westerly along the continental shelf. The remainder of this flow (30 percent or less) swings northward as part of the Georges Bank circulation and may eventually flow into the Gulf of Maine or continue around the bank and exit at other locations. In water depths greater than 100 m along the southern flank it is likely that flow is down the slope toward the submarine canyons and deeper waters. Tidal currents are moderately strong in the shallow areas of the bank above 60 m depth and decrease appreciably with increasing depth. Currents within the submarine canyons on the southern flank of Georges Bank periodically attain high velocities associated with tidal fluctuation, internal waves, turbidity flows, and storms.

Georges Bank is a highly productive biological environment which supports a substantial fishing industry of great commercial importance to New England. Substantial research efforts have been made to determine the underlying basis for the high level of biological production and understand the fluctuations (principally decline) of harvestable stocks, so that these stocks can be managed effectively. Much of the sustained high level of production is attributed to upwelling of nutrient-laden water supporting a high level of phytoplankton production which in turn is the principal source of energy for pelagic and benthic food webs. The benthic invertebrate fauna on the southern flank is generally characterized by high biomass in shallow water but is rapidly diminished with increased depth. Sea scallops and American lobster are the two most important commercially exploited shellfish resources. Surveys indicate a broad pattern of groundfish abundance in the southern part of the bank that corresponds with that of the benthic invertebrates; namely, ● bundance is highest in shallow water and declines with increased depth. Most of the southern area (including the Lease Sale 42 area) is moderately low to moderately high in resource abundance compared to other portions of the bank. Yellowtail flounder is the most important species over most of this area (less than 60 m depth) while silver hake, pollock, and other bakes are also important, especially in deeper water.

There is concern that exploration and development of petroleum resources on Georges Bank would ● dversely ● ffect the living marine resources not only on the bank but also in surrounding ● rus. It has been hypothesized that drilling fluids discharged into the water column ● t various locations and water depths within the lease ● reas would eventually be transported through the very productive submarine canyons to deeper offshore waters, ● long the southern flank ● cross Great South

Channel and deposited in the Mud Patch, or along the southern and western sides of the bank with ultimate deposition in the Gulf of Maine.

Current plans for exploratory drilling and low to high estimates of development drilling in the Lease Sale 42 EIS were used in the formulation of a drilling scenario. The physical-chemical and biological fates and effects of drilling fluids were assessed in two contexts. The first was in terms of fate and effects in the vicinity of a single drilling operation that could be extrapolated to cumulative fate and effects within the lease area for the drilling scenario. The second was in terms of ultimate fate and effects in hypothesized areas of eventual deposition. These assessments necessitated making numerous assumptions in the absence of reliable or directly applicable data. In several instances lower and upper limits of effects were developed; upper limits are thought to be tom="-tively high (highly unlikely to occur) and lower limits are thought to be more probable. ,

The principal sources of information applicable to assessment of drilling effects on Georges Bank are studies conducted to monitor drilling fluids dispersion during drilling of C.O.S.T. well Atlantic G-1 in 48 m of water on the bank and the more extensive studies conducted in the middle Atlantic before, during, and after drilling of an exploratory well in 120 m of water. The results of these studies were used to estimate the fate and effects of drilling in the lease area, allowing for reasonable differences in environment and drilling depths.

As in other regions, there is little basis for concluding that significant adverse effects would be detectable among various components of the pelagic community (plankton and nekton) in the Georges Bank lease area. The benthic environment within the lease area will be affected by the deposition of drill cuttings and mud solids with associated chemical additives. Drill cuttings and mud solids will affect sessile and sedentary benthic invertebrates due to burial and suffocation. A larger area of bottom will be affected by deposition and transport of fine solids and adsorbed chemicals which in sufficient concentration may have chronic or acutely toxic effects on benthic invertebrates.

It is anticipated that adverse impacts on the benthic environment will be greater around wells drilled in deeper water despite the fact that benthic organisms are more abundant in shallow water. This is because higher rates of dispersion and dilution occur in shallow water, thus reducing the exposure of the smaller area of bottom initially affected. In deeper water increased trajectory through the water column disperses drilling fluids over a larger area of bottom initially but dispersion following deposition would take longer than in shallow water.

Based on benthic invertebrate biomass data for the lease area and lower and upper estimates of bottom area potentially affected, projections of drilling impacts were made. A well drilled in 55 m of water would potentially affect a bottom area of 0.01 to 0.17 km^2 which supports 8,675 to 133,070 kg of benthic invertebrate biomass. Most exploratory drilling is expected to occur at an average depth of 85 m where 0.28 to 1.77 km^2 of bottom and 62,770 to 392,310 kg of invertebrates would be potentially affected. In deep water (?3S m) about 2.01 to 8.04 km^2 of bottom would be affected which would support 118,630 to 474,506 kg of invertebrates. During the 3-yr period of exploration it is expected that 13.4 to 70.06 km^2 of bottom and 2,175 to 12,779 mt of invertebrate biomass would be potentially affected. Since drilling during the development phase will be concentrated at the locations of platforms, the total area of bottom potentially affected will be relatively law compared to the number of wells drilled. Uncle% the low development scenario, about 8.4 to 44.6 km^2 of bottom and 1,343 to 7,847 mt of invertebrate biomass would be potentially affected. Under the high development scenario, about 25.1 to 126.9 km^2 of bottom and 3,580 to 20,551 mt of invertebrate biomass would be potentially affected. For the 11- to 14-yr period in which exploration and development would occur, approximately 3,519 to 33,300 mt of benthic invertebrate biomass would potentially be affected. This amounts to about 320 to 2,379 mt/yr.

It can be assumed that there is a 10-percent conversion of prey biomass to predator biomass. Thus, the 320 to 2,379 mt of invertebrate biomass potentially affected each year would support 32 to 238 mt of benthic fish or invertebrate predators and scavengers. For comparison, the total United States and foreign fleet catch of these organisms averaged 188,736 mt from 1972 to 1975. In this context, the potential impact on the benthos could reduce feeding opportunities for some 0.02 to 0.13 percent of the benthic fish and invertebrate catch. Because of the conservatism of assumptions made at every step in the development of this scenario, it is highly unlikely that quantities of fish and shellfish actually lost to the effects of the effluents would approach even this low figure (0.02 percent).

To assess potential effects of accumulation of drilling mud within the Mud Patch and Gulf of Maine (hypothetical sinks), it was assumed that all of the mud solids and chemicals discharged over the life of the field would be deposited in each ares and mixed in the top 5 cm of sediments. The resultant concentration% of barium, chromium, aad zinc, the most abundant metals, would probably be undetectable against ambient and analytical variation. Similar Calculations were made for Gilbert Canyon; it was assumed that about 11 percent of the drilling fluids produced in 1 yr would be deposited in the heed of the canyon. Concentration of chromium and zinc would be undetectable against ambient variation,- but concentrations of barium would be above ambient. In reality, the amount of drilling fluids transported toward the canyons would be dispersed through more than one canyon; thus metals concentrations would be lower yet. Increased concentrations of suspended solids in the canyons might occur, but background data are not yet available to judge the significance of this effect. A significant increase of suspended solids could ● dversely affect sessile filter-feeding organisms such as corals and sponges. A field study is in progress to ● ssess this possible impact.

Field and laboratory studies of the effects of drilling muds and natural sediments contaminated by heavy metals provide ample ●ridencas of bioaccumulation (uptake) of these metals in tissues of benthic organisms. Circumstantial evidence suggests that biomagnification of these metals through the food web does not occur. However, a definitive study of this problem has yet to be done so that biomagnification of metals on Georges Bank remains an improbable but unresolved issue.

CONCLUSIONS

1. Extensive laboratory testing has demonstrated that the bulk of materials present in drilling fluids (e.g., barite, bentonite) are relatively nontoxic chemically but contribute to high suspended solids levels. Other materials present in lesser quantities such as heavy metals, biocides, and petroleum hydrocarbons may be highly toxic. Whole mud mixtures are less toxic than the sum of the toxicities of their component parts because physical and chemical associations formed within the mixture render many components biologically unavailable.

2* All field and monitoring studies have shown that high rates of dilution of drilling fluids occur within a relatively short distance of the discharge and that background levels for most water quality parameters are approached within 1,000 m.

'3. The likelihood of significant impacts on pelagic plankton and nekton from drilling mud and cuttings discharges appears remote, both in lower Cook Inlet and on Georges Bank.

4* The degree of impact of drilling fluids and cuttings on benthic and demersal species is highly dependent on a number of local environmental variables (depth, current and wave regimes, substrate type, etc.) and on the nature and volume of the discharges including cutting sizes and the depth of the downpipe. Impacts can be considered to fall into two relatively distinct categories: short-term, lethal effects of mud toxicity and burial by mud and/or cuttings; and longer term effects of chemical contamination and physical alteration of the sediments which may alter recruitment.

5. The majority of benthic impact studies to date have found little evidence of significant physical, chemical. or biological effects extending beyond 800 to 1,000 m downcurrent from a well site. In moderate- to low-energy environments, accumulations of cuttings and muds on the bottom have the potential to cause relatively severe impacts on infauna up to perhaps 100 to 200 m downcurrent of the discharge and less severe changes in species composition and abundance perhaps as far as 1 to 3 km downcurrent.

6. Effects resulting from physical alteration of the bottom, e.g., cuttings or mud accumulations that change sea floor topography and/or grain size, will tend to revert toward their predrilling conditions at a rate directly proportional to the rate at which natural processes (e.g., currents) are affecting the bottom, i.e., over a period of weeks or months in dynamic areas and over a period of months or years in less dynamic areas.

7. The hydrodynamic regime in the majority of lower Cook Inlet is ideally suited to minimize the impact of drilling fluid and cuttings discharges. Cuttings impinging on the bottom will be rapidly dispersed and worked into the bottom sediments by near-bottom currents and biogenic activity. Mud solids will be scrubbed from the cuttings, resuspended, and transported from the site. Only in the southern and northeastern portions of the Cook Inlet lease area will bottom conditions allow accumulations of mud and cuttings that could affect benthos for up to 1 to 2 yr.

   If the total quantity of mud released from the BLM (1976) development scenario for lower Cook Inlet were transported to the most likely ultimate sink (Shelikof Strait) and spread evenly on the bottom, it would be undetectable chemically and insignificant biologically.

8. The benthic environment in the Georges Bank lease area will be affected by the deposition of drill cuttings and mud solids with associated chemical additives. Drill cuttings and mud solids will affect sessile and sedentary benthic invertebrates due to burial and suffocation within 100 to 200 m of the discharge. A larger area of bottom, up to 1 to 3 km downcurrent, may be affected by deposition and transport of fine solids and adsorbed chemicals which in sufficient concentration may have chronic or acutely toxic effects on benthic invertebrates. It is anticipated that adverse impacts on the benthic environment will be greater around wells drilled in deeper water although benthic organisms are more abundant in shallow water.

   The 320 to 2,379 mt of invertebrate biomass conservatively estimated as potentially affected each year during exploration and drilling would support 32 to 238 mt of demersal fish or invertebrate predators and scavengers. In this context, the potential impact on the benthos would affect 0.02 to 0.13 percent of the total U.S. and foreign demersal fish and invertebrate catch from 1972 to 1975.

9. The likelihood of measurable or biologically significant quantities of drilling fluids accumulating in the potential depositional sinks off Georges Bank is remote. Minor effects in the submarine canyons are possible under the conservative worst-case impact scenario but the real likelihood is considered to be very low.

ADDITIONAL AREAS FOR RESEARCH

Examination of existing literature and the development of conservative (worst-case) estimates for environmental impacts indicate insignificant impacts would result from drilling mud discharges. While conclusions may remain essentially the same with additional Information, the following areas of research may be appropriate in order to supplant the assumptions that were made.